AB 1632 ASSESSMENT OF CALIFORNIA'S OPERATING NUCLEAR PLANTS

EXECUTIVE SUMMARY

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AB 1632 (Chapter 722, Statutes of 2006) authorizes the California Energy Commission to work with other public entities and agencies, including the California Seismic Safety Commission, to gather and analyze information related to the vulnerability of the state's largest baseload power plants to a major disruption due to a seismic event of plant aging. In places where this report contains input from staff of the Seismic Safety Commission, it does not reflect input from the full California Seismic Safety Commission nor have the Commissioners approved the report. While Seismic Safety Commission staff members are licensed professionals familiar with certain aspects of seismic systems, they do not perform engineering, geological or other licensed work. Consequently, their input does not constitute work by licensed professionals on the Seismic Safety Commission or its staff. The Seismic Safety Commission does not assume responsibility for the accuracy, integrity or reliability of any aspect of the contractor's report nor does the Seismic Safety Commission regulate, certify, approve or disapprove of this report.

The Study Team

This report is the product of a collaborative effort by individuals at MRW & Associates, Inc. (MRW), ABS Consulting (ABS), Aspen Environmental Group (Aspen), Ventyx (formerly Global Energy Decisions), and EllerStone D'Paul, Inc. collectively referred to as the "Study Team." Individuals from these companies provided expertise for various aspects of this interdisciplinary report. MRW provided policy and economic expertise as well as overall project management; ABS provided expertise in nuclear plant engineering, geology, and seismology; Aspen contributed environmental and socioeconomic expertise; Ventyx assisted with the resource planning analysis; and EllerStone D'Paul provided research and editorial support. A list of the individuals that contributed to this report is provided below.

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Abstract

This consultant report was prepared in response to Assembly Bill 1632 (AB 1632), which directed the California Energy Commission to assess the potential vulnerability of the state's two operating nuclear power plants to a major disruption due to a seismic event or plant aging; to assess the impacts of such a disruption on system reliability, public safety, and the economy; to assess the costs and impacts from nuclear waste accumulating at these plants; and to evaluate other major issues related to the future role of these plants in the state's energy portfolio (Blakeslee, Chapter 722, Statutes of 2006). The report considers the seismic vulnerabilities of the nuclear plant sites, structures, and spent fuel storage facilities and the vulnerability of the plants to age-related degradation. The report also considers the impacts of a major disruption at the plants on the reliability of California's transmission grid and power supply. Finally, the report considers a number of policy areas related to California's operating nuclear plants, including the cost, land use, and local economic impacts of nuclear waste accumulation at the plant sites; the economic and environmental tradeoffs among alternative power supply options; and potential implications of renewing the operating licenses of the nuclear plants.

Keywords

nuclear, nuclear power, Diablo Canyon, San Onofre Nuclear Generating Station, SONGS, Hosgri, Fault, seismic, earthquake, tsunami, operating basis earthquake, safe shutdown earthquake, design basis, Kashiwazaki-Kariwa, aging, degradation, vulnerability, Nuclear Regulatory Commission, NRC, nuclear waste, waste storage, waste disposal, Department of Energy, DOE, spent fuel, safety culture, Independent System Operator, CAISO, transmission, production simulation, outage, replacement power, reliability, low-level waste, land use, property values, renewable power, life cycle, once-through cooling, license renewal, relicensing, electricity, policy, California, dry cask, independent spent fuel storage installation, ISFSI, greenhouse gas emissions, GHG emissions

Executive Summary

In 2006 the California Legislature enacted Assembly Bill 1632 (AB 1632).[1] The legislation directed the California Energy Commission (Energy Commission) to assess the potential vulnerability of the state's largest baseload power plants, which are the two operating nuclear plants, to a major disruption due to a seismic event or plant aging.[2] The Energy Commission was also directed to assess the impacts that such a disruption would have on system reliability, public safety, and the economy; assess the costs and impacts from nuclear waste accumulating at these plants; and evaluate other major issues related to the future role of these plants in the state's energy portfolio.

The state's two operating nuclear plants, Pacific Gas & Electric's (PG&E) Diablo Canyon Power Plant (Diablo Canyon) and Southern California Edison's (SCE) San Onofre Nuclear Generating Station (SONGS), account for 12 percent of the state's overall electricity supply and, by some measures, 24 percent of the state's low-carbon electricity supply.[3] A major disruption of California's operating nuclear plants could result in a shutdown of plant operations for several months to more than a year or even cause the retirement of one or more of the plants' reactors. Because these plants are so important to the state's electricity supply, California needs a long-term plan to prevent major disruptions and to be ready should a disruption occur.

This report, *AB 1632 Assessment of California's Operating Nuclear Plants*, provides information to policymakers and stakeholders about Diablo Canyon and SONGS to assist energy policy planning. A key element of the report is a review of existing scientific studies concerning the potential vulnerability of SONGS and Diablo Canyon to a major disruption due to a seismic event or plant aging.

Study Approach

This assessment, as prescribed in AB 1632, relies on existing literature, studies, and data where possible. The interdisciplinary Study Team reviewed materials that include academic and scientific journal articles, reports, and studies; federal, state, and local governmental studies, reports, bulletins, planning documents, and budgets; federal and state regulatory proceeding filings and rulings; data provided by the nuclear plant owners; and many articles and reports. Despite the depth and breadth of data and literature reviewed, the Study Team in some instances encountered areas where data are either limited or unavailable. For these areas, the report identifies questions and issues that merit additional review and analysis.

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[1] AB 1632 (Blakeslee, Chapter 722, Statutes of 2006).

[2] AB 1632 directs the Energy Commission to assess "large baseload generation facilities of 1,700 megawatts or greater." Besides Diablo Canyon and SONGS, there are two generating facilities (Alamitos and Moss Landing) that have a nameplate capacity greater than 1,700 MW. However, because both of these facilities operate below a 60% capacity factor, they are not considered baseload generation and were therefore excluded from the study.

[3] California Energy Commission. "2007 Net System Power Report." CEC-200-2008-002-CMF. April 2008, pages 4-5. <http://www.energy.ca.gov/2008publications/CEC-200-2008-002/CEC-200-2008-002-CMF.PDF>.

For the seismic vulnerability assessment, the Study Team provided early drafts to several seismic staff experts in the California Seismic Safety Commission, the California Coastal Commission, and the California Geological Survey. These experts reviewed the drafts and provided comments on the literature reviewed by the Study Team and the team's preliminary assessment of the seismic vulnerabilities of Diablo Canyon and SONGS.

Members of the public also contributed to this assessment by identifying studies for review and providing comments on a draft study plan. In order to maintain the independence of the assessment, the Study Team did not meet with the nuclear plant owners or other interested parties during the development of the draft report. The plant owners, members of the public, and interested stakeholders will be provided the opportunity to submit written comments on the draft report until October 2, 2008.

Seismic Vulnerability Assessment

The seismic vulnerability assessment undertaken for this study was performed in two steps. In the first step, the Study Team considered the geology and seismic hazards in the vicinity of Diablo Canyon and SONGS. In the second step the Study Team assessed the seismic design of the power plants, the spent fuel storage facilities located at the plants, the transmission systems leading to and from the plants, and the access roadways for the plants. From these reviews, the Study Team developed an assessment of the plants' vulnerabilities to earthquakes and secondary seismic hazards.

The main findings of the seismic vulnerability assessment are:

1. PG&E, via the Long-Term Seismic Program (LTSP), has extensively explored the seismology and geology of the Diablo Canyon site. SCE does not have an analogous program to PG&E's LTSP, and much less is known about the SONGS seismic setting. New information on ground motion and blind thrust faulting has eroded the perceived safety margins of SONGS. The vulnerability of the plant to seismic hazards cannot therefore be ascertained without further investigations into the plant's seismic setting and an assessment of the implications of new research on seismology, geology, and ground motion for the plant's safety and reliability.

2. The Hosgri Fault dominates the seismic hazard at Diablo Canyon. Uncertainties exist regarding the regional tectonic setting surrounding Diablo Canyon and the nature of the Hosgri Fault. Current published data, much of which has been developed through the LTSP, support the interpretation that the Hosgri Fault is a strike-slip fault.[4] There is, however, a currently less-favored model of the fault that considers the Hosgri Fault a thrust fault. If it is a thrust fault, the seismic hazard at Diablo Canyon could be greater than currently anticipated.

3. Diablo Canyon is located within the San Luis-Pismo geologic block. There is a need to better define the deep geometry of bounding faults of this block and to better

[4] This interpretation was adopted in a recent consensus report by the U.S. Geological Survey, the California Geological Survey, and the Southern California Earthquake Center.

understand the lateral continuity of these fault zones. Although these fault zones are unlikely to replace the Hosgri Fault as the dominant source of seismic hazard at the plant, improved characterizations of these fault zones would refine estimates of the ground motion that is likely to occur at different frequencies. This would be significant for future engineering vulnerability assessments.

4. A consensus fault model for California indicates that the bounding faults of the San Luis-Pismo block have lower dip angles toward one another than has previously been modeled by PG&E. This fault geometry suggests that the occurrence of an earthquake directly beneath Diablo Canyon of similar nature to the 2003 San Simeon earthquake cannot be conclusively ruled out. An assessment of this possibility, if conducted, should include an analysis of the expected ground motions and vulnerabilities of plant components that might be sensitive to pulse-type, long-period motions in the near field of an earthquake rupture.

5. Updates to the Diablo Canyon probabilistic seismic hazard assessment have concluded that the plant was built with sufficient safety margin to accommodate ground motions from the Hosgri Fault, assuming up to a 33 percent chance of thrust faulting. Future study with newer technologies, such as three-dimensional geophysical seismic reflection mapping, could resolve questions about the characterization of the Hosgri Fault and might change estimates of the seismic hazard at the plant. Similarly, such imaging at strategically chosen locations could serve to prove or disprove the existence of subsurface faults in the San Luis–Pismo tectonic block and could also serve to refine knowledge of the deep geometry, continuity, and interaction of poorly expressed faults that comprise the structural boundaries of the San Luis–Pismo Block.

6. Establishment of a permanent global positioning system (GPS) array in the onshore region of the Diablo Canyon site could clarify the nature of local crustal movements through repeated surveys. Results of these surveys might alter fault parameters that are used in existing seismic hazard assessments.

7. The major uncertainties regarding the seismology of the SONGS site relate to the continuity, structure, and earthquake potential of a nearby offshore fault zone that connects faults in the Los Angeles and San Diego regions. There is also uncertainty regarding the potential for unknown ("blind thrust") faults near the plant. Well planned, high-quality three-dimensional seismic reflection data at strategically chosen locations may resolve many of the remaining uncertainties and might change current estimates of the seismic hazard at the plant.

8. New seismologic and geologic information that has emerged since SONGS was built indicates that SONGS could experience larger ground motions from earthquakes than had been anticipated at the time the plant was designed. This does not necessarily imply that the plant is unsafe; however, it raises safety and reliability concerns that warrant further study.

9. In the years since Diablo Canyon and SONGS were built, scientists have learned more about the ground motions that could result from an earthquake rupture. One important finding is that ground motion can be highly variable in the region near a rupture, with

significant amplification of ground motion in some areas. These effects have already contributed to a higher revised seismic hazard assessment at SONGS. It will be important for PG&E and SCE to continue to evaluate the implications of new approaches to incorporating estimates of ground motion variability in the near-source region of faults.

10. The U.S. Geological Survey (USGS), California Geological Survey, and the Southern California Earthquake Center have developed a detailed, updated ("UCERF-2") database of faults and rupture probabilities in California. This database, used in conjunction with USGS models, would provide additional useful information regarding the seismic hazards at Diablo Canyon and SONGS. To obtain accurate seismic hazard data, the USGS models must be modified to reflect site-specific conditions at the plants.

11. In addition to the direct hazard from earthquake ground motion, there are secondary seismic hazards that could impact the nuclear plants. Liquefaction and landslides do not appear to be significant hazards at Diablo Canyon or SONGS. There is less certainty regarding the tsunami hazards at the sites because currently available tsunami studies for both plants are at least 10 years old and do not take advantage of modern tools that could improve the quality of the assessments, such as second-generation tsunami run-up maps being prepared by the University of Southern California and new data from the National Oceanic and Atmospheric Association.

    Updated tsunami hazard assessments are important for both plants, but they are most critical for SONGS. This is because the SONGS seawall is just three feet higher than the largest tsunami that was thought to be possible at the site based on the original tsunami hazard studies conducted during the plant's design. These studies did not consider the hazard from submarine landslides, which could be large events. PG&E is currently reassessing the tsunami hazard at Diablo Canyon; SCE is not planning a reassessment of the tsunami hazard at SONGS.

12. The non-safety related systems, structures, and components (SSCs) of the plants are the greatest sources of seismic-related vulnerability for SONGS and Diablo Canyon. The electrical switchyards are particularly vulnerable to damage. Damage to these systems would not pose a safety hazard to the public; however, it could result in outages of weeks or months for repairs.

13. Seismic design standards of non-safety related SSCs have evolved significantly since Diablo Canyon and SONGS were designed and licensed. Given the evolution of seismic design standards, non-safety related SSCs at Diablo Canyon and SONGS may be less seismically robust than if those same SSCs were built to current standards. A full understanding of the vulnerability of Diablo Canyon and SONGS to a major disruption of operations as a result of seismic events is incomplete without an analysis of the implications of seismic design changes that have occurred since these plants were designed and built. Such an analysis would need to consider any retrofits to SSCs that PG&E and SCE may have undertaken.

14. The estimated times to repair or replace components within a nuclear power plant may range from one week to as much as several years. The determining factor most likely

would be the location of the damage, i.e., whether the repair is one the nuclear side or the non-nuclear side of the power plant. One implication of the plant shutdown at the Kashiwazaki-Kariwa nuclear plant in Japan following an earthquake in 2007 is that plant shutdowns are not only tied to equipment repair times but also can be driven by regulatory and political concerns.

15. The spent fuel pools and dry cask storage facilities at Diablo Canyon and SONGS have been designed to sustain a design basis ("safe shutdown") earthquake at the plants, and they are unlikely to fail due to an earthquake. In addition, the dry cask storage facilities were built to accommodate newly characterized effects that can amplify earthquake ground motion and which could impact the seismic hazard of the facilities. Of the two types of storage, spent fuel pools are associated with a higher degree of overall risk, and they are also known to experience "sloshing"—the spillage of water from the pool—during earthquakes.

Seismic Hazards at Diablo Canyon

The offshore Hosgri Fault zone, roughly six to eight kilometers west of Diablo Canyon, creates the primary seismic hazard at the plant site. Uncertainty exists regarding the tectonic setting of this fault zone with much of the scientific discussion centering on whether the fault is a lateral strike-slip fault or a thrust fault. The distinction is significant for the ground motion hazard at the Diablo Canyon site: a strike-slip fault is steeply (i.e. close to vertically) inclined, and a thrust fault has a shallower angle and extends diagonally beneath the surface. If the Hosgri Fault were a thrust fault with an eastward dip, the fault would extend closer to the Diablo Canyon site, and the ground motion resulting from an earthquake could be greater.

Geologic and seismologic research literature supports the interpretation that the Hosgri Fault is characterized by strike-slip faulting. Experts with the USGS, the California Geological Survey, and the Southern California Earthquake Center have accepted the strike-slip characterization for the Hosgri Fault. Other scientists, however, disagree with this characterization.

The implications of a thrust fault characterization for the seismic vulnerability of Diablo Canyon are uncertain. PG&E evaluated the seismic hazard at Diablo Canyon from the Hosgri Fault for probabilities of 67 percent strike-slip faulting and 33 percent thrust faulting. PG&E found that there was sufficient safety margin in the plant design to accommodate the resulting ground motion, even though this motion was greater than had been anticipated when the plant was designed. PG&E has not published an analysis showing the implications of 100 percent thrust faulting on the safety of the plant, although such an interpretation is extreme in the context of the current professional consensus.

Another potential seismic hazard at Diablo Canyon occurs from the possibility of an earthquake directly beneath the plant. Based on seismologic interpretations and conclusions from investigations of the 2003 San Simeon earthquake that occurred approximately 35 miles north of the Diablo Canyon site (magnitude 6.5), the tectonic setting where this earthquake occurred appears similar, in part, to the local tectonic setting of Diablo Canyon. The deep geometry of faults that bound the San Luis-Pismo block, where Diablo Canyon sits, is not well enough understood to rule out a San Simeon-type earthquake directly beneath the plant. It is necessary to better define the deep geometry of bounding faults of the San Luis-Pismo block and to better

understand the lateral continuity of these fault zones. Although these fault zones are unlikely to replace the Hosgri Fault as the dominant source of seismic hazard at the plant, improved characterizations of these fault zones would refine estimates of the ground motion that is likely to occur at different frequencies. This information would be significant for engineering vulnerability assessments.

The Diablo Canyon seismic setting has been extensively studied, largely under the Long-Term Seismic Program.[5] Further study using advanced technology may help resolve the Hosgri Fault debate. For example, high quality three-dimensional seismic data could aid in identifying the true dip and structure of the Hosgri Fault, direct imaging of subsurface structure at Diablo Canyon could determine if faults exist near the site that do not break to the surface, and establishment of a permanent GPS array in the region surrounding the plant could refine models of tectonic movements in the plant vicinity.

Finally, characteristics of ground motions that could result from earthquakes is an area of continuing research. Recent studies have found that ground motion in close proximity to a fault could be stronger and more variable than previously thought. This could be important at Diablo Canyon since the plant lies within eight kilometers of the Hosgri Fault.

Seismic Hazards at SONGS

In contrast to the Diablo Canyon site, a recent review by the California Coastal Commission in connection with the construction of a proposed spent fuel storage facility states "there is credible reason to believe that the design basis earthquake approved by U.S. Nuclear Regulatory Commission (NRC) at the time of the licensing of SONGS 2 and 3 … may underestimate the seismic risk at the site."

As newer seismologic and geologic data become available, the emerging concern appears to be an eroding safety margin at the SONGS site. The estimated frequency of a design basis ("safe shutdown") earthquake decreased from 1 in 7,194 years in a 1995 study to 1 in 5,747 years in a 2001 study. Underground ("blind thrust") faults in the vicinity of SONGS have been postulated since the plant was built. This new information does not necessarily mean that the facility is unsafe. Since the plant was engineered with a large margin of safety, it likely will withstand earthquakes of greater magnitude and frequency than originally expected. However, the possibility that the safety margin is shrinking suggests that further study is necessary to characterize the seismic hazard at the site, especially since much less is known about the seismic setting of SONGS than the seismic setting of Diablo Canyon. There is no program at SONGS similar to PG&E's Long-Term Seismic Program at Diablo Canyon.

An important element of the seismic hazard at SONGS is the continuity, structure, and earthquake potential of the South Coast Offshore Fault zone and the faulting that connects the Newport-Inglewood Fault in the Los Angeles region with the Rose Canyon Fault in the San Diego region. Similar to the Diablo Canyon area, direct high-quality subsurface imaging of the offshore zone is lacking. Well planned, high-quality three-dimensional seismic reflection data at

[5] The Long-Term Seismic Program is a unique program developed in response to the discovery of the Hosgri Fault during the licensing of Diablo Canyon.

strategically chosen locations may hold potential for resolving both the continuity and sense of motion along the offshore Newport-Inglewood Rose Canyon Fault zone.

Also similar to Diablo Canyon, SONGS is located within 10 kilometers of a fault, and new research on ground motion near an earthquake rupture is relevant to the seismic hazard of the plant. When SCE incorporated some of these developments into the seismic hazard assessment for SONGS, SCE found that the safety margins at the plant are less than previously believed.

Tsunami Hazards at Diablo Canyon and SONGS

PG&E is currently conducting a study to reassess the tsunami hazard at Diablo Canyon. The most recent study, from the early 1990s, concluded that the plant was designed to sustain the largest tsunami that can be expected at the site.

It appears that SCE has not reassessed the tsunami hazard at SONGS since the plant was designed. Since then, scientists have learned that submarine landslides can generate large local tsunamis. Tsunami run-up maps that are being prepared by the University of Southern California will incorporate expected hazards from such near-to-shore landslides. Currently, it is not possible to determine whether these new maps will result in significantly revised estimates of the tsunami hazard at SONGS. Even a moderate increase in the estimated maximum tsunami run-up could raise significant concerns about the adequacy of the site's seawall.

For both plants, the currently available tsunami hazard assessments do not take advantage of recently developed tools that could provide more accurate assessments. The use of probabilistic hazard assessments, inundation modeling, and data from the National Oceanic and Atmospheric Administration's Short-Term Inundation Forecast for Tsunamis system could improve the quality of future assessments.

Vulnerability of Power Plant Buildings and Structures

The safety-related systems, structures, and components of Diablo Canyon and SONGS are designed to remain safe during safe-shutdown earthquakes of magnitude 7.5 on the Hosgri Fault and 7.0 on the South Coast Offshore Fault Zone, respectively. These earthquakes are expected to be the largest magnitude earthquakes that could impact the plants given what is currently known about the geology of local faults.

Earthquakes with magnitudes equivalent to the safe-shutdown earthquakes would likely cause serious damage to Diablo Canyon or SONGS with the damage centered on the non-nuclear areas of the plants. The safety-related portions of the plants—the reactor, primary steam supply, containment, and associated equipment—are expected to withstand safe-shutdown earthquakes without damage that would impact safety. Notably, the largest earthquakes experienced at SONGS and Diablo Canyon have been significantly less than the plants' safe-shutdown earthquakes. The Study Team cannot assess the plants' true seismic vulnerabilities since seismic evaluations of the non-safety portions of the plants were not available to the Study Team.

The switchyards of the plants could be particularly vulnerable to earthquake damage because the equipment configuration and the dispersed and interconnected nature of the switchyard facilities make them vulnerable to ground motion. In part, the degree of damage that could be sustained will depend on the extent to which SCE and PG&E have upgraded their plants'

switchyard equipment to meet the newest seismic design standards. Failure of a switchyard could result in a loss of power from the plants even if the reactor units remain safe and undamaged.

The turbine building and tank areas might also be susceptible to damage. The turbine building at Diablo Canyon is large with an expansive open space inside. The turbine building's roof could collapse in an earthquake. At SONGS, the tank areas for the condensate storage tank and the refueling water storage tank are low-lying areas susceptible to water damage in the event of a tsunami that exceeds the design basis. Ground movement near the support pads for the tanks could cause underground pipes to burst and damage the tanks.

Diablo Canyon or SONGS could be shut down following earthquakes for as little as one week to as much as four years for repairs or component replacement. Estimates of time to repair or replace nuclear plant components are very uncertain since this information is not readily available. Other factors affecting the duration of a shutdown include the amount of time needed to investigate the plant for damage and the need for design and backfitting efforts. Public or regulatory concerns also could delay the restart of the power plant. A collaborative study involving the utilities, manufacturers, and researchers with the appropriate expertise could be beneficial to estimating power plant restart time.

There are many lessons to be learned from the experience of the Kashiwazaki-Kariwa Nuclear Power Plant (KK NPP) and the 2007 Niigata Chuetsu-Oki earthquake. The KK NPP experienced ground motions significantly higher than the design basis ground motion and yet suffered no significant damage to safety-related components. Nevertheless, more than a year after the earthquake, the KK NPP remains shut down. Extensive investigations appear to be the primary cause of the lengthy shut down, suggesting that repairing or replacing damaged components may not be the primary driver of how long a nuclear power plant is shut down following a major seismic event. Research and investigations into the earthquake and the root causes of damage at the nuclear power plant are ongoing; the Energy Commission and California's nuclear plant owners should stay informed as new information becomes available.

Vulnerability of Spent Fuel Storage Facilities

There are two general types of spent ("used") nuclear fuel storage, pool and dry cask storage. Diablo Canyon and SONGS currently use pools for spent fuel storage; however, dry cask storage facilities have also been constructed for the increasing amount of spent fuel stored on site. The greatest risk for spent fuel pools is the loss of water or the loss of active cooling. If not mitigated, such an event could result in overheating of the stored spent fuel and the subsequent release of radioactive material. The design of spent fuel storage pools reduces the possibility of drainage leading to water levels lower than the stored fuel; nevertheless, loss of any amount of water is undesirable. The spent fuel pools at Diablo Canyon and SONGS are supported on or partially embedded in the ground to increase their ability to withstand seismic ground motion beyond their design basis.

Because of the lack of a permanent spent fuel disposal facility, the spent fuel pools at Diablo Canyon and SONGS have been "re-racked" to provide increased storage capability by placing the fuel assemblies closer together. The more densely configured spent fuel pools are considered to have a higher degree of risk than a spent fuel pool that has a more open racking

arrangement. While regulations permit Diablo Canyon and SONGS to use re-racking, a loss-of-coolant event in a re-racked spent fuel pool could result in extensive radiation release and contamination.

An earthquake or other impact to a spent fuel pool could result in the spread of radioactivity if contaminated water spills from the pool, as occurred during the July 2007 Niigata Chuetsu-Oki earthquake in Japan. Spilled water in one reactor building leaked into the Sea of Japan from leaks in the reactor building floor. Although the SONGS and Diablo Canyon spent fuel pools are designed to curb the effects of sloshing, PG&E is investigating the water-tightness of conduits in its reactor buildings.

In general, a dry cask storage facility is considered to have a lower degree of overall risk than a spent fuel pool. Over the last 20 years, there have been no radiation releases from a dry cask storage facility that have affected the public, no radioactive contamination, and no known or suspected attempts of sabotage. A major study on the risks of dry cask storage by Robert Alvarez, a Senior Scholar of Nuclear Policy at the Institute for Policy Studies, suggested that the use of dry cask storage at a nuclear power plant has the potential to reduce the overall risk associated with at-reactor storage of spent fuel, including the risk of seismic and terrorist events, since dry cask storage would allow the spent fuel pools to be returned to their original configuration and design loading.

Dry cask storage probabilistic risk analyses performed by the NRC and the Electric Power Research Institute (EPRI) concluded that there is a greater risk of an event leading to public harm during cask loading and transportation, which occur primarily during the first year of operation, than from routine operations. During the cask loading process, spent fuel is exposed and in motion, which increases the possibility for accidents.

The design of Diablo Canyon's dry cask storage facility incorporated a number of seismic safety features. These features were included after analysis of near-source fault ruptures showed the potential for types of ground motion to which the dry cask storage facility is more sensitive than the power plant. The SONGS dry cask storage facility was built to higher than required seismic standards at all frequencies. In reviewing the facility's seismic design, the California Coastal Commission concluded that even an earthquake much larger or closer than the design earthquake would not produce ground shaking that would exceed the design of the facility.

Although the primary focus of this report's vulnerability assessment of the spent fuel storage facilities was earthquake-related, the AB 1632 Study Team also reviewed published risk analyses for terrorist events or sabotage at dry cask storage facilities. Limited information is available on the vulnerability of dry cask storage to sabotage, which is consistent with the National Academies' finding when it conducted a study of spent fuel storage safety. While terrorist scenarios have been postulated that could release a significant amount of cesium into the environment, an assessment of the likelihood of such scenarios occurring has not been publicly released.

Vulnerability of Roadways and Transmission Systems

The primary concerns with seismic vulnerability of roadways serving Diablo Canyon and SONGS is reduced ability for emergency personnel to reach the plants and for the local

community and plant workers to evacuate. Diablo Canyon is served by a two-lane asphalt road. During an emergency, this restricted access could result in traffic congestion and increase the potential for traffic accidents and further congestion. At SONGS, access roadways have a large capacity to bring in emergency supplies and relief personnel, but, if the emergency impacts nearby residents, there could be an unprecedented amount of traffic traveling through this corridor to escape a threatening situation. If the traffic overwhelmed the highway system, it could halt highway access and impede emergency response. This occurred in Texas and Louisiana ahead of the 2006 hurricanes.

The distributed nature of the transmission system makes the transmission system relatively more vulnerable than a nuclear plant to terrorist attack, but such an attack would not result in high human or environmental risk. Transmission towers and poles are not very susceptible to earthquake damage. However, as discussed above, switchyards are likely to be damaged during large earthquakes.

Plant Aging and Reliability Assessment

The AB 1632 Study Team assessed the vulnerability of California's nuclear plants to extended outages caused by plant aging-related degradation and evaluated the reliability implications of an extended outage. The main findings of the Study Team are:

1. Aging plant components must be adequately monitored, maintained, and repaired to have a safe and reliable nuclear power supply. Unchecked age-related degradation could have significant long-term implications for safety and plant reliability.

2. Effective maintenance and a strong safety culture are critical to keeping Diablo Canyon and SONGS operating safely and reliably. The NRC has raised concerns about the safety culture at SONGS and has required SCE to create a plan to improve safety culture at the plant. Diablo Canyon appears to have a relatively effective safety culture and benefits from the oversight of the Diablo Canyon Independent Safety Committee. There is no similar independent safety oversight committee for SONGS.

3. The workforces at Diablo Canyon and SONGS are aging, and large numbers of staff will soon retire. It is critical to the ongoing reliability and safety of the plants that programs to transfer knowledge from retiring workers to new workers are successful and that strong safety cultures are maintained throughout this shift in the plants' workforces.

4. Simulations find that no electricity supply shortages would occur as the result of either Diablo Canyon or SONGS being unexpectedly shut down for an extended period in the near term, nor would remedial action, such as additional demand response, energy efficiency, or additional capacity be needed for reliability purposes.[6] Replacement power for either plant would be supplied mostly by combined cycle natural gas-fired plants, which are more expensive to operate and which emit more carbon dioxide than nuclear plants.

[6] The simulations modeled specifically the year 2012.

5. The simulations did not assess local reliability impacts of an extended outage at either of the nuclear plants or the availability of adequate generation resources after 2012. More complete studies and detailed modeling will be needed periodically to reassess the availability of replacement power at a system and local level as supply and demand conditions evolve and local transmission constraints change.

6. A prolonged shutdown of Diablo Canyon would not pose reliability concerns. However, a prolonged plant shutdown at SONGS could result in serious grid reliability shortfalls unless transmission infrastructure improvements are completed. Replacement power for SONGS would be available.

Vulnerability to Plant Aging-Related Degradation

The state's nuclear plants are now approaching their fourth decade of operation. As they age, their systems, structures, and components are all subject to age-related degradation, which, if unchecked, could lead to a loss of function and impaired safety.

There is a clear correlation between the age of a nuclear plant and the number of degradation occurrences it experiences. Effective maintenance programs and regulatory oversight are critical to ensure that aging plant equipment and components are identified and either repaired or replaced before the reliability and safety of the plant are jeopardized. Unchecked age-related degradation could have significant long-term implications.

Nuclear plants are baseload units and are planned to operate as much as possible. Any increase in the amount of the time a plant is unavailable or is forced to operate at less than full capacity is reflected in a reduced capacity factor.[7] Reductions in capacity factor over time may thus provide the first indication of an impact of age-related degradation. Capacity factors at Diablo Canyon and SONGS have increased significantly since the early years of plant operation, and both plants achieved five-year average capacity factors of approximately 90 percent. This does not necessarily indicate the absence of plant degradation, but it suggests that, up to now, operational improvements and reductions in down time for plant maintenance and refueling have more than compensated for degradation-related operational losses.

Researchers generally agree that age-related degradation is of greater concern for passive rather than active components. In the 1990s, NRC-sponsored research found that piping, steam generators, and passive components of the reactor pressure vessel comprised over half of nearly 500 reported degradation occurrences at nuclear plants in the U.S. Problems with reactor coolant systems and reactor vessels/internals have contributed to the greatest losses in energy production at nuclear plants nationwide. Careful monitoring of these components is crucial. In addition, EPRI's groundwater protection guidelines should be followed to prevent inadvertent releases of tritium on account of degraded materials or operational failures.

Plant component aging problems have surfaced at some U.S. nuclear plants. Davis-Besse, Vermont Yankee, Oyster Creek, and Indian Point have all received scrutiny by the NRC,

[7] The capacity factor is defined as the total energy production divided by the total possible energy production from the plant in the given period.

government agencies, and/or watchdog groups concerned that different types of age-related degradation are eroding plant safety. The implications for Diablo Canyon and SONGS are twofold. First, the same unanticipated age-related degradation of some plant components or systems could be occurring at the California plants. Second, a serious incident or the identification of a safety hazard at one plant could result in a regulatory requirement for more extensive inspections, repairs, and even outages at similar plants nationwide.

Maintenance plays a central role in mitigating age-related degradation and component failure. All units at Diablo Canyon and SONGS have achieved the highest level of the NRC's maintenance-related performance indicators since the second quarter of 2006, when a new performance-tracking system was initiated. A key element of an effective maintenance program is the plant's safety culture (a strong "safety-first" dedication and accountability among plant workers). However, the NRC has raised concerns about the safety culture at SONGS and has required SCE to create a plan to improve safety culture at the plant. The Institute for Nuclear Power Operations, an industry-funded oversight agency, has also identified safety concerns at SONGS, including an unusually high rate of employee injury.[8] A strong safety culture is a key element of an effective maintenance program, and problems with safety culture have been linked to the high profile operational difficulties at the Palo Verde Nuclear Generating Station and the extensive degradation uncovered at Davis-Besse. Diablo Canyon, which has had no NRC violations since 1995, appears to have a relatively effective safety culture. In this regard, Diablo Canyon benefits from the oversight of the Diablo Canyon Independent Safety Committee, which investigates concerns that do arise. SONGS may benefit from a similar independent safety oversight committee.

The workforces at Diablo Canyon and SONGS are also aging, and large numbers of staff will soon retire. Both utilities have instituted programs for the retiring staff to pass on their institutional knowledge to newer staff. It is critical to the ongoing reliability and safety of the plant that these programs are successful and that strong safety cultures are maintained throughout this shift in the plants' workforces.

Impacts of a Major Disruption at Diablo Canyon and SONGS

If an earthquake, age-related plant or equipment failure, or other event leads to an outage at one or both of the nuclear plants, the power from the impaired units would need to be replaced with power from other sources. Actions at other plants not directly related to the in-state nuclear plants could also result in a shutdown. For example, a major safety-related event at a nuclear power plant elsewhere in the country could lead to a general shutdown of other nuclear

[8] The results of Institute for Nuclear Power Operations (INPO) reviews are confidential, and the Energy Commission and the California Public Utilities Commission usually do not have access to information about these reviews. (Recent limited information releases by SCE and PG&E are exceptions.) In *Nuclear Power in California: 2007 Status Report*, MRW & Associates recommended that the Energy Commission "work with federal and state regulators, nuclear plant owners, and the Institute for Nuclear Power Operations to develop a means for usefully incorporating results of Institute for Nuclear Power Operations review and ratings of reactor operations into a meaningful public process while maintaining the value of these reviews as confidential and candid assessments." The Study Team agrees with this recommendation.

plants for an indefinite period of time. The reliability, cost, and environmental implications of an extended outage would depend on what time of the year the outage occurred and what replacement power was available.

When any of California's nuclear reactors are not operating, the power they produce must be replaced with power from other sources. PG&E and SCE generally schedule refueling outages and other maintenance shutdowns to avoid periods of peak demand and reduce the cost of replacement power. Unplanned outages can occur at anytime. The experiences of nuclear plants nationwide indicate that most unplanned outages last just a few days, although many plants have experienced significant operational disruptions lasting a year or longer, mostly from component degradation.

To assess replacement power options in the event of a lengthy, unplanned outage at one or both of California's nuclear plants, the Study Team simulated the operations of the electricity market for the year 2012 with and without one or both of the nuclear plants operational. The simulations suggest that no electricity supply shortages would occur as the result of either Diablo Canyon or SONGS being unexpectedly shut down for an extended period in 2012, nor would remedial action, such as additional demand response, energy efficiency, or additional capacity be needed for reliability purposes.

Based on simulations, replacement power in the event of a year-long outage at either Diablo Canyon or SONGS in 2012 would be supplied mostly by combined cycle natural gas-fired plants. Approximately 55 to 62 percent of the increased generation would come from in-state gas-fired plants, while the remainder would come from out-of-state gas-fired plants along with a small amount of increased coal generation. The cost of that replacement power would include the operating costs of in-state units and market costs to acquire power from out-of-state.[9] For a year-long loss of either nuclear plant, the simulations found that these costs would be $470 million higher than the cost to generate power from the nuclear plant. The added cost would increase average rates for customers of either PG&E or SCE/SDG&E by approximately half a cent per kilowatt-hour (kWh) while the outage continued. Plant repair costs likely would further increase rates.

An outage would also pose environmental consequences, since the replacement power would be largely natural gas-fired. The simulations found that an outage at either nuclear plant would increase in-state greenhouse gas emissions from power generation by seven to eight percent, or roughly 4.3 to 4.7 million tons of CO_2. Out-of-state replacement generation would add an additional 2.2 to 2.8 million tons of CO_2, for a total greenhouse gas impact of approximately 7 million tons of CO_2.

The 2012 simulation finding regarding available replacement power in the event of an outage at either nuclear plant is similar to current assessments of the California Independent System Operator that show sufficient reserve margins to accommodate the loss of either or both nuclear plants. This assessment of near-term replacement power options is not applicable to the post-

[9] The modeling assumes that incremental power from in-state resources can be acquired at the cost of service (i.e. are owned by the utilities or under a tolling contract) while incremental power from out of state must be purchased at market rates calculated internally within the MARKETSYM model.

2012 period and does not consider local transmission constraints that may restrict the deliverability of power to certain areas. More complete studies will be needed periodically to reassess the availability of replacement power at a system and local level given updated supply and demand conditions and local transmission constraints.

Previous studies have shown that while Diablo Canyon represents a significant generation resource and supports power flows through Path 15 and Path 26, the plant is not needed to maintain reliable operation of the transmission system. During a major disruption at Diablo Canyon, replacement power can be supplied by existing and new resources, albeit at additional cost and with a greater environmental impact since most of the replacement power would come from natural gas-fired plants. SONGS, on the other hand, appears to be a more integral part of the Southern California transmission system, and when it is shut down, imported power flows are also restricted. While replacement power for SONGS would be available (at similar costs and environmental impacts as for Diablo Canyon), a prolonged shutdown could cause serious grid reliability shortfalls unless transmission system infrastructure improvements were made. The extent of the transmission system changes would depend on the transmission configuration in place at the time of the SONGS shutdown.

Economic, Environmental, and Policy Issues Assessment

The AB 1632 Study Team assessed the costs and impacts from nuclear waste accumulating at Diablo Canyon and SONGS and evaluated other major issues related to the future role of these plants in the state's energy portfolio. The main findings of the Study Team related to these areas are:

1. The accumulation of nuclear waste at Diablo Canyon and SONGS is a long-term concern in the absence of a federal repository for disposing of spent fuel. If delays continue and spent fuel from SONGS has not been transferred to a repository within 40 years and from Diablo Canyon within 50 years, the spent fuel stored in dry casks on-site may need to be repackaged or the current spent fuel storage containers may need to be bolstered. This waste ultimately must be transported off-site, and spent fuel could require additional repackaging prior to transport. The long-term storage, packaging, and transport of this waste add to the expense and the risk of nuclear power in California.

2. PG&E is planning to build sufficient on-site dry cask storage so that Diablo Canyon can continue operating past the plant's current license period or the spent fuel pool can be decommissioned when the current license expires without additional storage being required. Based on SCE's current plans for dry cask storage, SCE will run out of spent fuel storage space at SONGS several months before the end of the plant's current operating license.[10] At that time, the plant will not be able to continue operating and the

[10] SCE is expected to run out of storage capacity towards the end of 2021, and the earliest feasible date for a repository opening is sometime after 2017, with a more likely opening date sometime after 2020 (see Appendix A and *Nuclear Power in California: 2007 Status Report)*. It is thus unlikely that sufficient spent fuel will be moved from SONGS to a repository before SCE runs out of storage capacity.

spent fuel pool will not be able to be decommissioned unless SCE builds additional on-site dry cask storage or secures offsite storage.

3. Currently, there is no low-level waste disposal facility in the U.S. available for California low-level waste except for the least radioactive grade ("Class A") of waste. Other classes of low-level waste (Class B and C) therefore must remain at the nuclear plant sites until a new or existing facility agrees to accept this waste. This does not pose a significant problem at present because the volume of this waste is relatively small, and the waste can be safely stored on site. However, the plants cannot be fully decommissioned until the waste is removed from the plant sites. In addition, given the scarcity of disposal options for low-level waste, the cost to dispose of the waste during plant decommissioning could be higher than currently anticipated. Indeed, low-level waste disposal costs have risen significantly in recent years, and estimates of disposal costs that were established in the most recent regulatory proceeding on decommissioning costs in 2005 are outdated.

4. The experiences of several communities in other parts of the U.S. suggest that a dry cask storage facility at a plant site should not prevent the full decommissioning of the remainder of the plant site and the conversion of most of the site to alternative, productive uses. More study is required to assess the impact of a dry cask storage facility on local property values, business, and tourism, as current academic research into this issue is very limited.

5. From a pure resource potential perspective, given adequate time California could license and build new renewable generation to replace the energy from Diablo Canyon and SONGS. However, since there are no large-scale renewable units with the same characteristics as baseload nuclear plants, current renewable technologies would require support of some natural gas-fired units to replace all the attributes of the nuclear plants. In addition, sufficient planning, siting, and construction time would be needed to develop these resources and any necessary transmission infrastructure. Based on current prices and technologies, replacing power from Diablo Canyon and SONGS primarily with renewable power would increase the overall cost of power to consumers. It would also replace certain environmental impacts, such as the adverse impacts from once-through cooling and nuclear waste generation, with other adverse impacts, such as avian mortality from wind towers, habitat fragmentation and risks of soil and water contamination from solar thermal plants, and greenhouse gas emissions from backup natural gas-fired plants. A more detailed study of power generation options is needed to quantify the reliability, economic, and environmental impacts of replacement power options.

6. One of the challenges in replacing the nuclear plants with renewable power generating facilities would be the different impacts of this decision on different communities. If the new plants were built in California, the total economic benefit from employment and taxes statewide would be comparable to the benefits currently provided by the nuclear plants. Many of these benefits would likely be transferred from the coastal communities near Diablo Canyon and SONGS to communities in inland southern California and throughout the state. Recent announcements of several planned large-scale solar

facilities in San Luis Obispo County suggest that renewable power development could benefit San Luis Obispo County, thereby limiting the transfer of benefits away from the County.

7. The economic impacts of closing Diablo Canyon could be offset by economic gains from alternate uses of the plant site, other commercial or industrial development elsewhere in the county, or a potential increase in property values as a result of the plant closure. Without such offsets, the loss of the plant would have a significant impact on the county's economy. The loss to the San Diego and Orange County economies from a closure of SONGS would be much less significant since these economies are more diversified and less dependent on the nuclear plant.

8. A key uncertainty in assessing the economic benefits to keeping Diablo Canyon and SONGS operating through a 20-year license extension is the reliability of the plants as they age. If the plants continue to operate reliably and do not require additional large capital improvements, the cost of power from the nuclear plants will likely remain lower than the cost of power from new renewable resources. However, significant equipment failures could result in extended outages and expensive repairs. As discussed earlier, effective plant maintenance and a strong safety culture are critical to keeping the plants operating safely and reliably as they age.

Nuclear Waste Accumulation at Diablo Canyon and SONGS

Diablo Canyon and SONGS produce significant quantities of radioactive waste in the form of spent fuel and other radioactively contaminated materials. These wastes must be carefully handled, stored, transported, and disposed of in order to protect humans and the environment from exposure to radioactive materials. Spent nuclear fuel, which is extremely radioactive, must be stored in a water-filled pool for a minimum of five years following removal from the reactor core to shield against high levels of radiation.

As previously discussed, Diablo Canyon and SONGS lack sufficient spent fuel pool capacity to store the quantity of spent fuel produced over the period of their operating licenses, which extend into the 2020s. As a result, PG&E and SCE have been forced to increase the on-site storage capacity for spent fuel by constructing dry cask storage facilities.

PG&E and SCE have taken different approaches for the design and use of on-site dry cask storage facilities at Diablo Canyon and SONGS. PG&E has designed and permitted a dry cask storage facility for Diablo Canyon that will allow the utility to transfer and store 100 percent of the spent fuel produced during the current operating license. This would allow PG&E to decommission Diablo Canyon's spent fuel pool at the end of the current license if needed. SCE has designed a dry cask storage facility for SONGS with a capacity to store 36 percent of the spent fuel generated during the current license period and intends to rely on its spent fuel pool to store the remaining spent fuel. Additional storage space would be required if SONGS were to continue operating past its current license or if SCE wanted to decommission the SONGS spent fuel pools before off-site spent fuel storage is available. Moreover, the total planned combined storage capacity at SONGS will be sufficient to store just 98 percent of the spent fuel expected to be produced during the plant's current operating license. In order to accommodate the

remaining spent fuel, SCE will need to secure offsite storage or develop additional capacity. SCE has not yet determined how it will manage the extra spent fuel.

The costs for constructing and loading the dry cask storage facilities are substantial. On a present value basis, the total cost is $160 million for Diablo Canyon and $300 million for SONGS. Since the dry cask storage facility at SONGS is just 40 percent the size of the Diablo Canyon facility and nearly twice as expensive, the SONGS facility is three to four times as expensive per fuel assembly.

In June 2008 the U.S. Department of Energy (DOE) filed a license application for a permanent geologic repository for spent fuel at Yucca Mountain, Nevada. If the license is granted, Yucca Mountain will begin operations most likely after 2020, over 20 years after the January 1998 statutory and contractual deadline for beginning to accept spent fuel from utilities. PG&E and SCE have sued DOE for reimbursement of their ISFSI costs, claiming that this delay represents a breach of contract. PG&E received a favorable judgment that provides for reimbursement of certain dry cask storage costs while denying other claims. PG&E is currently appealing the decision. A trial date to hear SCE's claim has not been set.

Utility dry cask storage is an interim solution for waste disposal. PG&E's facility is designed for a lifetime of 50 years, and the canisters used in SCE's facility are designed for a lifetime of 40 years. If the spent fuel is not transported off-site within the design lives of the dry cask storage facility components, the spent fuel may need to be repackaged on-site and transferred into new storage canisters, or the current canisters or other cask storage facility components may need to be bolstered. At this time there are no estimates as to how long the spent fuel will remain in interim dry-cask storage, and no additional off-site or on-site interim fuel storage facilities are being considered by either PG&E or SCE.

If a federal repository is established, spent fuel will need to be packaged for transport, aging, and disposal (TAD). DOE has not yet established federal TAD packaging requirements, forcing PG&E and SCE to move forward with dry cask storage cask designs that may not be compatible with the TAD requirements. The costs for transport of spent fuel to off-site storage or disposal facilities will be substantial, including costs for security, accident prevention, and emergency preparedness. Policies are being developed to federally fund state and county emergency response preparation; however, California has claimed that the proposed federal program may be insufficient, both in the planned timing of the grant program and the amount of the proposed grants for state planning and for training emergency response personnel to respond to potential accidents involving California's spent fuel shipments.

Low-level radioactive waste also requires care in handling, transport, and disposal. There are only three facilities in the U.S. that accept low-level waste for disposal and, as of June 30, 2008, only the Energy Solutions facility in Clive, Utah, accepts low-level waste from Diablo Canyon and SONGS. It is expected that Class A waste will continue to be shipped to Clive, Utah, but that Class B and C wastes (waste with higher levels of radioactivity) will be stored on-site at Diablo Canyon and SONGS until an alternate facility is available. The NRC is currently reviewing its policies regarding on-site low-level waste storage and expects to complete this task by the end of 2008.

Low-level waste disposal costs are relatively modest during ongoing plant operations. However, a substantial quantity of low-level waste will need to be disposed of when the plants are decommissioned, and the cost to transport and dispose of this waste, presuming a disposal facility is available, is expected to be hundreds of millions of dollars or more. Low-level waste disposal costs have been rising in recent years, and current estimates of disposal costs during decommissioning are based on outdated cost information. Costs could be substantially higher than estimated during the most recent California regulatory proceeding on decommissioning costs in 2005.

Land Use and Economic Implications of On-Site Waste Storage

There is considerable uncertainty as to when and if a geologic repository or other interim waste storage facility will allow the removal of spent fuel from the Diablo Canyon and SONGS plant sites. This raises questions about the land use and local economic implications of extended on-site waste storage. It is widely assumed that long-term storage of spent fuel at the plant sites will have a negative effect on future land uses, local property values, business, and tourism. Underlying this presumption is the perception that spent fuel storage creates health and safety risks that preclude certain land uses or depresses economic conditions.

The experience of several communities where nuclear power plants have been shut down and decommissioned but a dry cask storage facility remains does not support this presumption. Indeed, local communities near the Rancho Seco plant outside of Sacramento, California, and the Maine Yankee nuclear power plant have successfully converted the land once used for the power plant and immediately around it into areas that provide recreational or economically-productive mixed uses. The Connecticut Yankee nuclear plant site may also be developed soon. Accordingly, the presence of dry cask storage facilities at Diablo Canyon and SONGS after the plants are decommissioned should not prevent alternate uses from being established. The Diablo Canyon plant site will likely be converted to recreational use. The SONGS plant site, which is located on military land, will presumably remain under the control of the U.S. Navy. The Navy will have the option to use the land for military purposes, to lease or sell it to another party, or to open it for recreational use.

Even with a plant site converted to alternate uses, the question remains as to whether the continued presence of the spent fuel has a negative impact on property values, business, and tourism in the area. Academic research does not lead to a strong conclusion that a dry cask storage facility would negatively affect nearby property values. However, the available analytical studies are extremely limited and only partially relevant, and the available surveys appear to be unreliable predictors of economic effects. An analysis of property sales data and other economic indicators in areas where a dry cask storage facility is operating would provide a useful starting point to assess potential economic impacts of extended spent fuel storage at California's nuclear plants.

Power Generation Options

The California legislature, through Assembly Bill 32 (AB 32, 2006), has mandated greenhouse gas reductions statewide, and the California Air Resources Board and the Energy Commission are integrating this mandate into the state's energy policies. As the Energy Commission stated

in the *2007 Integrated Energy Policy Report*, "AB 32 forces California to determine how to meet its electricity needs in a way that leaves an ever-shrinking *greenhouse gas* footprint."[11]

The primary ways to meet California's growing energy demand while lowering greenhouse gas emissions are energy efficiency, renewable resources, and distributed generation.[12] From a pure resource potential perspective, given adequate time California could license and build new renewable generation to replace the energy from Diablo Canyon and SONGS. However, since there are no large-scale renewable units with the same characteristics as baseload nuclear plants, current technologies would require support of some fossil fuel units to replace all the attributes of the nuclear plants. Operational and local transmission issues must be studied more carefully to identify which attributes of these plants would need to be replaced should the plants be shut down. In addition, the costs of renewable energy are uncertain, and a switch to renewable power resources away from nuclear power could result in an overall increase in the cost of electricity. Technological advances could ameliorate some or all of the potential cost and reliability concerns.

No power generation technology is free of environmental impacts. A comparison of the life cycle greenhouse gas emissions for nuclear power, wind, solar photovoltaics, geothermal, and biomass shows that these technologies have comparable levels of life cycle greenhouse gas emissions. In addition, each of these technologies has some impact on the environment, affecting land, water, or wildlife. Moreover, the fossil fuel power plants needed to support many renewable units emit greenhouse gases and cause additional environmental impacts. Nuclear energy generation also imposes impacts from nuclear waste storage, transport, and disposal and from a potential major plant accident or terrorist event.

Life cycle analyses can provide decision-makers a clearer and more complete understanding of the health and environmental impacts of different generating technologies. However, the usefulness of these analyses in comparing technologies is constrained by widely varying methodologies and assumptions and, in many cases, limited data. Extreme care must be taken to interpret the results of such analyses in light of these limitations.

Local economic impacts of generating facilities can also be important factors in policy decisions about resource options. Replacing the nuclear plants with an equal mixture of in-state wind, solar thermal, geothermal, and biomass power would result in roughly the same overall tax and employment benefits to the state as provided by the nuclear plants. However, these benefits would be conferred to different localities. The communities currently benefiting from the nuclear plants would lose jobs and revenue unless the nuclear plants were replaced by other income-generating facilities. Notably, several large-scale solar projects are currently being planned in San Luis Obispo County.

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[11] California Energy Commission. *2007 Integrated Energy Policy Report*. CEC-100-2007-008-CMF, page 35.

[12] California law (Public Resources Code 25524) prohibits the permitting of land-use for a new commercial nuclear power plant until a federally approved means for the permanent disposal of spent fuel is available. This effectively excludes nuclear power as a means to meet California's growing energy demand.

Preliminary modeling suggests that replacing the state's two nuclear plants with renewable generation and using existing fossil-fuel units for reliability support could incur significant costs. Additional modeling is needed to fully understand the economic and environmental tradeoffs, as well as the implications on the California power grid, of permanently retiring Diablo Canyon and SONGS.

License Renewal Issues for State Policymakers

Diablo Canyon and SONGS have been operating for roughly half of their 40-year initial license periods, and PG&E and SCE are exploring the feasibility of seeking 20-year license renewals from the U.S. NRC. If granted, license renewals could keep Diablo Canyon and SONGS in operation until the early to mid 2040s.

The decision whether or not to renew the Diablo Canyon and SONGS operating licenses will have a significant impact on the state's power supply portfolio and on the communities located near the reactors. Unfortunately, the full implications of this decision are unknown. Even the most straightforward question of how much power would be impacted by this decision cannot be answered with any certainty. While current production levels from the plants are known, it is unclear how performance will change as the plants age—no commercial reactor has yet operated for a full 60 years.

The cost of power from the nuclear plants over the license renewal period will be linked to the performance of the plants. If the plants maintain high levels of performance and safety and do not require significant repairs, the costs could remain comparable to current levels with relatively minor increases due to higher nuclear fuel costs and potentially stricter security requirements. However, degradation of major components or extended outages could result in much higher costs. In addition, the plants may be required to retrofit their once-through cooling systems prior to a license renewal. In a study for the Ocean Protection Council, Tetra Tech estimated that the retrofit and outage would cost a net present value of $2.6 billion at SONGS and $3.0 billion at Diablo Canyon.

In addition, it is important to consider the environmental impacts from plant operations over an extended 20-year license period, including once-through cooling ocean impacts and impacts from continuing waste accumulation at these plants. The extent of the impacts will depend on the outcomes of state and federal policies and requirements for once-through cooling and on whether a long-term solution to the waste disposal problem is found.

The impact that shutting down one or both of the plants would have on the reliability of California's electricity grid is unclear at this time. The impact will depend on what other generating and transmission resources are built or retired over the next two decades and on the pattern of population growth in the regions near the plants. This is an area that needs to be investigated further prior to any decision on license renewal.

The loss of the plants would mean the loss of high-paying jobs and tax revenues for the communities located near the plants. Given current economic conditions, this loss would be felt more strongly in San Luis Obispo County following the closure of Diablo Canyon than it would be in the much larger San Diego and Orange Counties following the closure of SONGS. Some or all of this loss could be recouped over time by the use of the reclaimed land for other income-

generating enterprises or by the development of renewable energy facilities elsewhere in the county to replace the nuclear units. It is also possible that some of this loss could by offset by a rise in property values, if current property values are depressed by the presence of the plants. However, additional study is required to assess whether this is the case and whether the closure of the plants would reverse this impact, especially if nuclear waste remains on-site.